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PROCESSING OF BIOMEDICAL WASTE IN PLASMA GASIFIER

V.E. MESSERLE*, A.L. MOSSE**, A.B. USTIMENKO°, O.A. LAVRICHSHEV°, Z. JANKOSKI°° AND R.V. BAIMULDIN°

** Combustion Problems Institute, Almaty, Kazakhstan; Institute of Thermophysics of SB RAS, Novosibirsk, Russia*
*** A.V. Luikov Heat and Mass Transfer Institute, NAS of Belarus, Minsk, Belarus*
° NTO Plasmotechnika LLC (Research & Development), Research Institute of Experimental and Theoretical Physics, al-Farabi Kazakh National University, Almaty, Kazakhstan
°° Department of Mechanical Enginering, University Department of Professional Studies, University of Split, Split, Croatia

SUMMARY: This report presents the results of thermodynamic analysis and experiments on gasification of Biomedical Waste (BMW) in plasma gasifier by the example fuelwood. Thermodynamic computation of plasma gasification of BMW revealed that synthesis gas utilizable in heat-and-power engineering, metallurgy and chemical industry can be produces from BMW. Air gasification of BMW allows producing synthesis gas with yield of 81.6% (CO - 41.9%, H_2 - 29.7%). Specific calorific value of synthesis gas is 9450 kJ/kg. Computed parameters of the processes of BMW plasma gasification in air were used to develop experimental plasma installation. Experiments on BMW plasma gasification were conducted in a setup composed of plasma gasifier of 50 kg/h productivity by BMW and DC plasma torch of 100 kW of electric power. As a result of air gasification of BMW in the experimental plasma gasifier synthesis gas of 71.1% (CO – 42.0%, H_2 – 25.1%) concentration was received. On the process optimal temperature (1600 K) specific power consumptions for plasma air gasification of BMW amount to 1.53 kW h/kg. Discrepancy between experimental and calculated data by the yield of synthesis gas was not more than 6%. Harmful impurities were revealed in neither gas no condensed products of BMW plasma gasification.

1. INTRODUCTION

In its development, humanity has reached a point where awareness of the limitation of natural resources and the need to take measures to preserve the environment have merged with the growing problem of recycling household and industrial waste and maximizing the use of secondary raw materials and energy resources. From renewable energy sources, the most important by annual increase in volumes is municipal solid waste (MSW) and fuelwood (FW). For example, in the world it has accumulated more than 2 billion tons of MSW. In Russia, approximately 57-60 million tons of MSW are generated each year, of which about 83% comes from the housing and communal services sector, the remaining 17% comes from the

commercial sector. Despite the decline in Russia's population, the amount of formation of MSW will grow for at least the next 10 years. It is estimated that the annual growth rate for this period will average 3.4%, in which case by the year 2025 the annual volume of MSW will exceed 70 million tonnes [1]. At present, about 94% of the Russian MSW is subject to disposal in landfills and dumps, 4% is involved in industrial processing and only 2% is processed using thermal processing technologies. In Kazakhstan, 97 million tons of domestic waste have already been accumulated. At the same time, about 6 million tons of household waste are generated annually, of which about 2% are processed [2]. In Belarus, 37 million tons of waste are generated annually, of which 25 million tons are sorted, and the rest are disposed of at 170 polygons [3]. The world annually produces about 1 billion tons of FW. The main part of the FW (80%) is wood and products of its processing (sawdust, bark, wood chips). The capacity of power stations operating on FW is 35 million kW. So, in the USA 4% of all energy is produced from FW. The most common FW processing technology is gasification [4, 5]. From 1 kg FW it is possible to obtain about 2.5 m^3 of energy gas, the main combustible components of which are carbon monoxide (CO) and hydrogen (H_2). Recently, plasma gasification of wastes has become widespread [6 - 12]. Plasma gasification achieves the maximum yield of synthesis gas ($CO+H_2$) by reducing the concentration of ballasting gases (CO_2 and N_2). However, in the post-Soviet areas, waste, including FW, is practically not used and the problem of their utilization is very relevant.

The aim of the work was to conduct complex thermodynamic and experimental studies of FW plasma processing, comparison of the calculated and experimental data and the development of technological process recommendations. In this paper we discuss the results of thermodynamic analysis of high-calorific fuel gas production by gasification of FW in air. Also experimental installation is presented and the results of experiments on gasification of FW in air plasma compare with the computation.

2. THERMODYNAMIC COMPUTATION

A typical chemical composition of FW is represented by the following components, wt.%: C - 49.88, O - 43.81, H - 5.98, N - 0.10, K_2O - 0.01, CaO - 0.12, MgO - 0.02, MnO - 0.01, Fe_2O_3 – 0.01, Al_2O - 0.01, SiO_2 – 0.01, SO_3 – 0.01, P_2O_5 – 0.02, Na_2O – 0.01. The organic part of FW is represented by carbon, oxygen and hydrogen with a total concentration of 99.7%, whereas the mineral part is only 0.3%

Software package Terra [13] was used to perform thermodynamic calculations of FW plasma air gasification. Calculations were carried out in the temperature interval 300 – 3000 K and a pressure of 0.1 MPa. The initial technological mixture with mass ratio FW to air equal 1 was used for air gasification.

The aim was to determine the integral parameters of the gasification process: equilibrium composition of the gas phase of the gasification products, the degree of carbon gasification and specific power consumption for the process.

Figure 1 shows the variation in concentration of gaseous components depending on the temperature of air gasification of FW. With increasing temperature the yield of the synthesis gas ($CO + H_2$) increases to a maximum at T = 1600 K. Maximal concentration of combustible components of synthesis gas reaches 81.6% (CO - 41.9%, H_2 - 29.7%). It should be note that already at 1200K the total concentration of synthesis gas is 81.3%, which differs little from its maximum value. The concentration of oxidants ($CO_2 + H_2O$) at these temperatures does not

exceed 0.7%. With increasing temperature, the concentration of synthesis gas is reduced slightly due to the appearance in the gas phase of atomic hydrogen (H), which concentration reaches 7.8% (T = 3000 K). Concentration of ballasting nitrogen (N_2) remains almost constant in the temperature range 1200 – 3000 K, being 27.8 – 26.7% respectively. The concentration of methane (CH_4) decreases sharply and at the temperature 1200 K converges to zero.

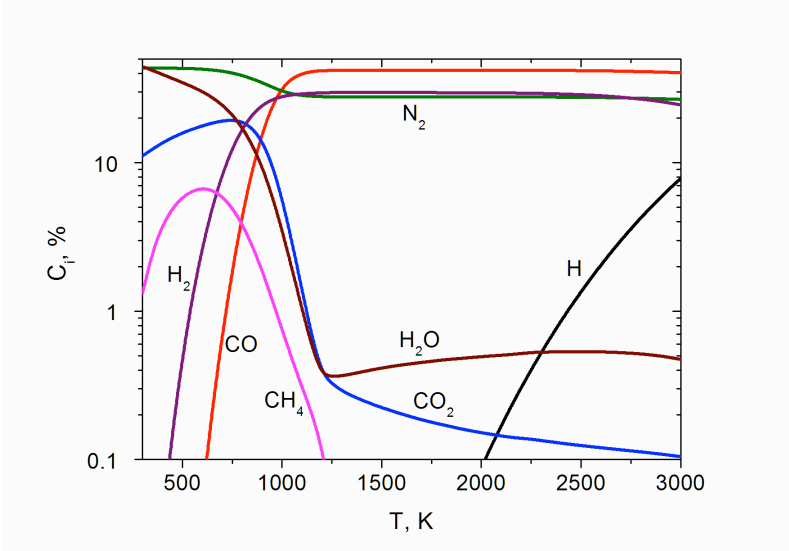

Figure 1. Variation in concentration of gaseous components depending on the temperature of FW air gasification.

The degree of carbon gasification X_C (Fig. 2) is determined from the carbon content of the solid residue. Specifically, X_C is calculated according to the following expressions: $X_C = \frac{C_{bas} - C_{fin}}{C_{bas}} \times 100\%$, where C_{bas} is the initial amount of carbon in the coal, and C_{fin} is the final amount of carbon in the solid residue. As appears from Fig. 2 carbon gasification degree amounts 100 % at a temperature 1200 K. It is seen that the carbon is completely transformed into the gaseous phase forming CO at a temperature higher than 1200 K. This provides a hundred percent carbon gasification

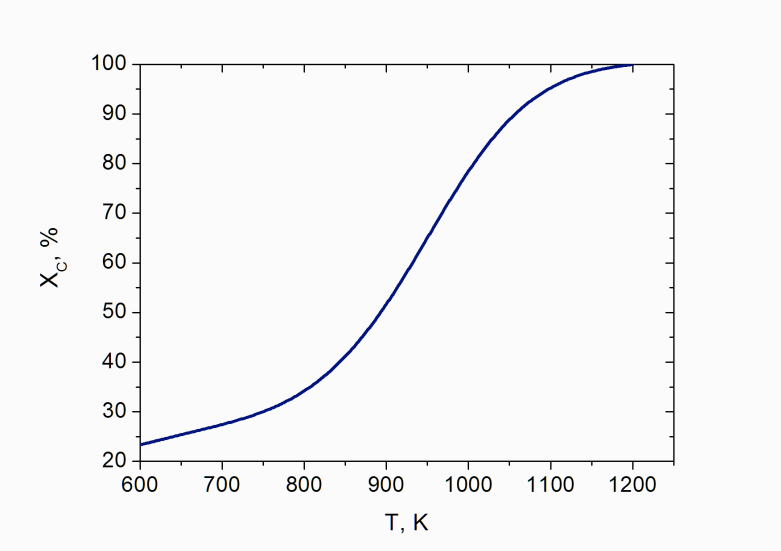

Figure 2. Carbon gasification degree dependence on temperature of FW gasification.

Specific power consumption (Fig. 3) was defined as the difference between the total enthalpy of the final (current temperature of the process) and initial (T=298 K) state of the system reduced to 1 kg of working substance (mixture of FW and plasma forming air). Specific power consumption for the process of FW gasification increases with temperature along the full its range. For the temperature T = 1600 K, at which the yield of synthesis gas reaches its maximum (Fig. 1), the specific power consumption for air gasification of FW constitute 1.25 kW h/kg. Such a moderate energy consumption for air gasification of FW associated with compensation of endothermic effect due to the heat of the oxidation reaction of carbon in air.

Found parameters and identified regularities of the process of FW plasma gasification were used to develop an experimental installation.

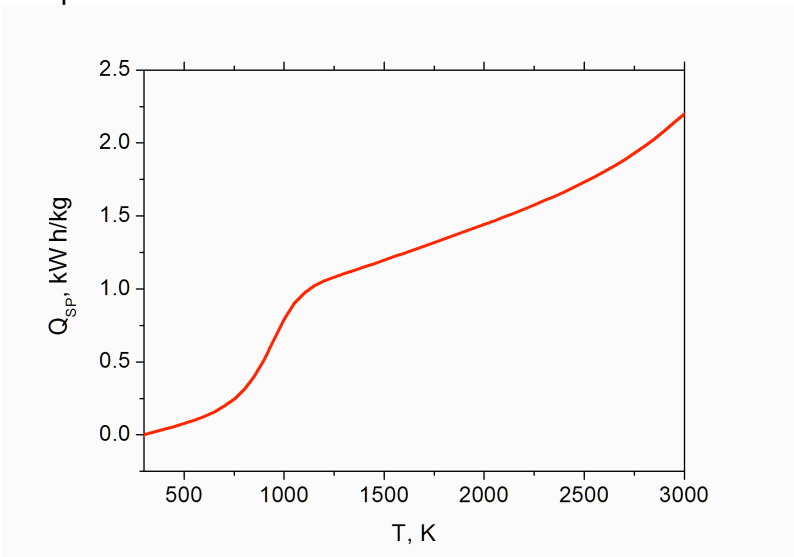

Figure 3. Specific power consumption for the process of FW plasma gasification dependence on temperature

3. EXPERIMENT

Experimental studies of FW gasification were performed on the installation (Fig. 4), main elements of which are a plasma chemical reactor (Fig. 5) with productivity by FW up to 50 kg/h and long live DC plasma torch of 70 kW nominal power [14]. To increase service life of the plasma torch a method of the plasma pyrolysis of hydrocarbon gases with the subsequent deposition of the condensed products of the pyrolysis on water-cooled copper electrodes of the plasma torch was developed. According to the method, a propane–butane mixture is fed into the zone of arc discharge between the cathode and anode. As a result, the vapor of carbon is formed in the cavity of the cathode and on the inner surface of the anode. Electron microscopy and Raman spectroscopy instrumental studies of the electrode coating showed that it consisted of the composite nanostructured carbon material including largely single-walled and multi-walled carbon nanotubes and other carbon forms with a certain amount of copper atoms intercalated in the carbon matrix. Experimental study of the long life plasma torch showed that at the plasma torch power of 72.6 kW (I=220 A, U=330 V), plasma forming air flow rates of 250 l/min and propane–butane flow rate of 1.8 l/min, temperature at the plasma torch nozzle exit section was 5500 K (Fig. 5). At resource tests of the plasma torch for 1000 hours the erosion of the copper electrodes was not fixed, as the true electrode functions were performed by regenerable nanocarbon coating of copper electrodes [15].

The composition of the experimental setup (Fig. 4), except the reactor 4 and plasma torch 1, includes the plasma torch power management system and systems of gas and water supply into the reactor and plasma torch and exhaust gas cleaning 7. Installation is equipped with sampling system of gas and condensed products of FW gasification process for their analysis [16].

Plasma reactor (Fig. 5) was designed for plasma gasification of FW. The reactor is a cube. It is lined by refractory bricks thickness of 0.065 m. A size of the inner side of the cube is 0.45 m. The reaction volume of the reactor is 0.091 м^3. Pipe for supplying of briquetted FW 2 can be used to measure the temperature inside the reactor using infrared pyrometer. Pyrometer Ircon Ultrimax Plus UX10P is used for temperatures from 600 to 3000ºC (873-3273 K). Metering error depends on temperature range and it is ±0.5% of measured value for temperature range up to 1500ºC (1773 K), ±1% for the range 1500-2000ºC (1773-2273 K) and it increases to ±2% for the temperature over 2000ºC (2273 K). Temperature resolution is not worse than 1ºC. The device is equipped with COM port for connection to computer, and the temperature can be controlled by RS-232C protocol during experiment and performs results in on-line regime. Sampling interval of the device is 0.5 s.

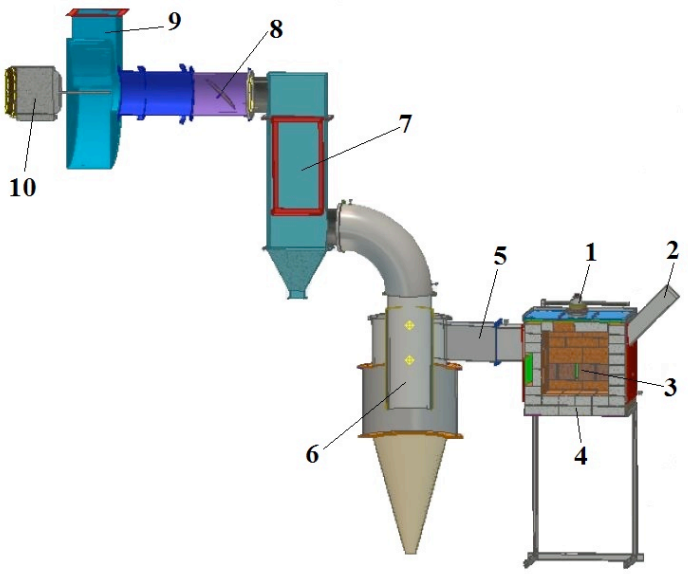

Figure 4. Layout of the experimental unit for plasma gasification of FW: 1 – arc plasma torch; 2 – pipe for supplying of briquetted FW; 3 – FW gasification zone; 4 – reactor; 5 – chamber for combustible gas removal from the reactor; 6 – cyclone combustion chamber; 7 – gas purification unit with a bag filter; 8 – control valve; 9 – ventilator of exhaust system; 10 – engine of the exhaust system.

The process of FW plasma gasification is as follows. After starting the plasma torch 1 and heating inner liner surface of the bottom of the reactor 4 prior to temperature 1215 K (about 15 minutes), FW briquettes are served into the gasification zone 3 through the pipe 2 (Fig. 4). Weight of each briquette is 0.33 kg. It takes two minutes to supply 5 briquettes. FW are gasified in the air plasma flame, providing an average mass temperature in the reactor volume up to 1600 K. Gaseous products are taken out of the reactor into the cyclone combustion chamber 6, and the condensed products accumulate in the bottom of the reactor. The combination of the zone of heat release from plasma flame with one of FW gasification 3 and slagging contributes to the intensification of FW processing. The cooled gaseous products enter the gas purification unit 7, after which via gas sampling system is supplied to the analyzer. Ventilation system 9 including and pressure control valve 8 provides a low pressure in the reactor up to 10 mm of water column.

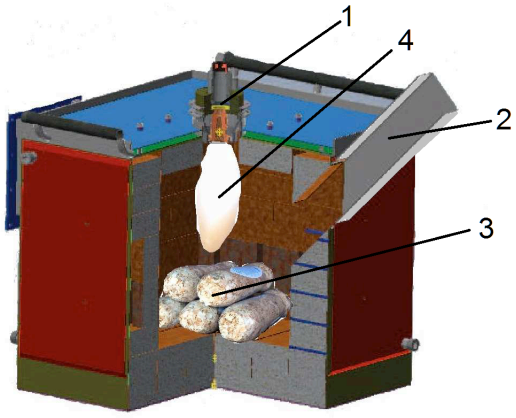

Figure 5. Scheme of the plasma reactor: 1 – arc plasma torch; 2 – pipe for supplying of briquetted FW; 3 – FW briquettes; 4 – plasma flame.

Figure 6 gives a perspective view of the reactor with lifted lid and plasma flame. As a result of FW plasma gasification synthesis gas was produced. Figure 7 shows the flame of gas exiting the pipe 2 at a short time disabling of exhaust system. It can be seen that the resulting fuel gas is intensively ignited in air. Measured temperature of this flame was 1600 K. During the experiment, the fuel gas is withdrawn using exhaust system. Measured temperature in the bottom of the reactor was 1560 K. Under the influence of air plasma flame, the weight average temperature in the reactor reached 1600 K, an organic part of FW was gasified and inorganic part (ash) was accumulated in the slag formation zone (Fig. 8) of the reactor and in the bag filter 7 (Fig. 4). The obtained synthesis gas was incinerated in cyclone combustion chamber 6. Combustion products were continuously withdrawn from the installation through the cooling and purification systems. The ash was removed from the reactor after shutdown of the plasma torch and cooling the reactor. The plasma torch was turned off 25 minutes after the download of the first FW briquette. 30 briquettes of total mass 9.9 kg were gasified during this period. FW briquettes consumption was 23.8 kg/h. Air flow rate through plasma torch was 23.6 kg/h.

By the results of experimental studies of FW plasma gasification plasma reactor operating conditions were determined, the exhaust gas analysis was performed, the samples of the condensed products were collected from slag formation zone of the reactor, and the residual carbon content in the slag was determined. Gas analysis performed on a gas chromatograph SRI 8610C, showed the following composition of the gas at the exit of gas purification unit, vol.%: CO – 42.0, H_2 – 25.1, N_2–32.9. Specific heat of combustion of the synthesis gas produced by air gasification amounts to 9450 kJ/kg. The total concentration of the synthesis gas was 77.1%, which agreed well with the thermodynamic calculations. The yield of synthesis gas according to the calculation at 1,600 K was 81.6% (CO - 41.9%, H_2 - 29.7%). Thus, the discrepancy between experiment and calculation by the yield of the target product (synthesis gas) did not exceed 6%. Concentration of thermodynamically predicted N_2 was 27.8%. This difference could be because of unguided dissolution of experimentally produced synthesis gas by ambient air.

Figure 6. Photo of the plasma torch in action with lifted lid of the reactor.

Figure 7. Photo of the combustible gas control flame from the pipe for supplying of briquetted FW.

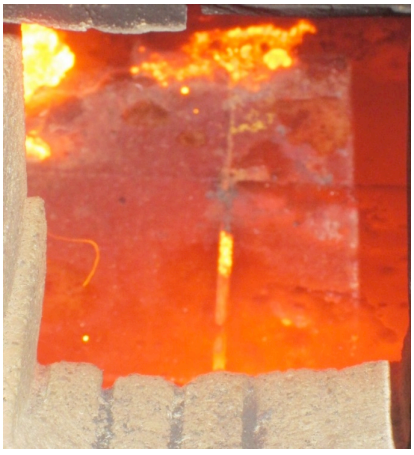

Figure 8. Photo of hot ash on the bottom of the reactor after plasma torch turn off.

After gasification 9.9 kg of FW 0.013 kg of ash was collected from the bottom of the reactor (Fig. 8). This quantity of ash is about 0.2% from initial quantity FW. Residual fly ash (0.1% of ash) was flowed away with exhaust gas. Measured with help of volumetrical orifice flow rate of exhaust gas was 48.3 kg/h. The discrepancy between experimental and calculated flow rate is 2%.

In the experiments, as well as in calculations, no harmful impurities were found in the products of FW plasma gasification. Carbon content of the slag in the sample was 1.13 wt.%, which corresponded to the degree of FW carbon gasification 96.6%. It was found using absorption-gravimetric method. The discrepancy between the experimental and calculated values of carbon gasification degree did not exceed 3.5%.

Specific power consumption for FW gasification in the plasma reactor according to the results of experiments amounted to 1.53 kWh/kg of working substance. Efficiency of plasma source was ignored when determining specific power consumptions. In the calculation specific power

consumption for air-plasma gasification of FW was 1.25 kWh/kg (Fig. 3). The discrepancy between the calculated and experimental values of specific power consumption for the process is 18%. It is due to the fact that in thermodynamic calculations the lowest possible energy consumption in an isolated thermodynamic system is determined without taking into account the exchange of heat and work with the environment. In practice, the plasma reactor itself, and the plasma torch are characterized by considerable heat losses to the environment with the cooling water.

4. CONCLUSIONS

Thermodynamic calculations showed that the maximum yield of the synthesis gas at plasma gasification of fuelwood in air medium is achieved at a temperature of 1600K.

At the air plasma gasification of FW synthesis gas with a concentration of 77.1% (CO – 42.0, H_2 – 25.1) can be obtained. Specific heat of combustion of the synthesis gas produced by air gasification amounts to 9450 kJ/kg.

At the optimal temperature (1600 K), the specific power consumption for air gasification of FW constitutes 1.53 kW h/kg.

Found parameters and discovered patterns of the process of plasma gasification of FW have been used to design an experimental plasma installation.

In the experiments, as well as in thermodynamic calculations, no harmful impurities were found in both gas and condensed products of FW plasma gasification. Utilizable synthesis gas was produced from organic matter of FW and neutral slag from the mineral matter.

Comparison of experimental results and calculations showed good agreement.

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REFERENCES

[1] http://www.ng.ru/energy/2017-04-11/11_6971_musor.html

[2] http://www.kp.kz/society/13260-kazakhstan-nameren-pererabatyvat-do-50-bytovykh-otkhodov]

[3] http://upack.by/stati/124.html]

[4] I. Karp, K. Pyanykh, A. Yudin “Biomass: Combustion and Gasification for Substitution of Natural Gas” Industrial Heating, pp. 39-42, (2013).

[5] R. Mourão, A.R. Marquesi, A.V. Gorbunov, G.P. Filho, A.A. Halinouski, C. Otani “Thermochemical Assessment of Gasification Process Efficiency of Biofuels Industry Waste with Different Plasma Oxidants” IEEE T Plasma Sci, vol.43, no.10, pp.3760-3767, (2015).

[6] V.A. Zhovtyansky, S.V. Petrov, Yu.I. Lelyukh, I.O. Nevzglyad, Yu.A. Goncharuk “Efficiency of Renewable Organic Raw Materials Conversion Using Plasma Technology” IEEE T Plasma

Sci, vol.41, no.12, pp. 3233-3239, (2013).

[7] A.N. Bratsev, V.E. Popov, A.F. Rutberg, S.V. Shtengel' "A facility for plasma gasification of waste of various types" High Temp+, vol.44, no.6, pp. 823-828, (2006).

[8] A.S. An'shakov, V.A. Faleev, A.A. Danilenko, E.K. Urbakh, A.E. Urbakh "Investigation of plasma gasification of carbonaceous technogeneous wastes" Thermophysics and Aeromechanics, vol.14, no.4, pp. 607–616, (2007).

[9] J. Heberlein, A.B. Murphy "Topical review: Thermal plasma waste treatment" J Phys D Appl Phys, vol.41, no.5, pp. 053001 (20 p), (2008).

[10] Youngchul Byun, Moohyun Cho, Soon-Mo Hwang, Jaewoo Chung "Thermal Plasma Gasification of Municipal Solid Waste (MSW), Gasification for Practical Applications, Dr. Yongseung Yun (Ed.)", ISBN: 978-953-51-0818-4, InTech, DOI: 10.5772/48537. Available from: http://www.intechopen.com/books/gasification-for-practical-applications/thermal-plasma-gasification-of-municipal-solid-waste-msw pp. 183–210, (2012).

[11] I.B. Matveev, S.I. Serbin, N.V. Washchilenko, "Plasma-Assisted Treatment of Sewage Sludge ", IEEE T Plasma Sci, vol. 44, no.. 12. pp. 2960-2964, (2016).

[12] Q. Zhang, L. Dor, D. Fenigshtein, W. Yang, W. Blasiak "Gasification of Municipal Solid Waste in the Plasma Gasification Melting Process" Appl Energ, vol.90. pp. 106–112, (2012).

[13] M. Gorokhovski, E.I. Karpenko, F.C. Lockwood, V.E. Messerle, B.G. Trusov, A.B. Ustimenko "Plasma Technologies for Solid Fuels: Experiment and Theory" Journal of the Energy Institute, vol.78, no.4, pp. 157-171, (2005).

[14] V.I. Golish, E.I. Karpenko, V.G. Luk'yashchenko, V.E. Messerle, A.B. Ustimenko, V.Zh. Ushanov "Long-Service-Life Plasma Arc Torch" High Energ Chem+, vol.43, no.4. pp. 318–323, (2009).

[15] A.M. Il'in, V.E. Messerle, A.B. Ustimenko "The Formation of Carbon Nanotubes on Copper Electrodes under the Arc Discharge Conditions" High Energ Chem+, vol. 44, no.4. pp. 326–331, (2010).

[16] V. E. Messerle, A. L. Mosse, A. B. Ustimenko "Municipal Solid Waste Plasma Processing: Thermodynamic Computation and Experiment" IEEE T Plasma Sci, vol. 44, no. 12. pp. 3017-3022, (2016).